Principles of Medical Imaging

K. Kirk Shung

Department of Bioengineering
Pennsylvania State University
University Park, Pennsylvania

Michael B. Smith

Department of Radiology
Milton S. Hershey Medical Center
Pennsylvania State University
Hershey, Pennsylvania

Benjamin M. W. Tsui

Departments of Biomedical Engineering and Radiology
University of North Carolina at Chapel Hill
Chapel Hill, North Carolina

Academic Press, Inc.
Harcourt Brace Jovanovich, Publishers
San Diego New York Boston London Sydney Tokyo Toronto

ATTACHMENT "D"

Cover photograph courtesy of Michael B. Smith. A computer model of the human head showing the naturally occuring magnetic field gradients found in all normal humans when exposed to a homogeneous, static magnetic field of 1 tesla. Each contour line describes a field change of 0.3 parts per million. The differences in the magnetic field are due to the magnetic susceptibility of the air–tissue interface associated with the sinus cavities in the head.

This book is printed on acid-free paper. ♾

Academic Press, Inc.
1250 Sixth Avenue, San Diego, California 92101-4311

United Kingdom Edition published by
Academic Press Limited
24–28 Oval Road, London NW1 7DX

Library of Congress Cataloging-in-Publication Data

Shung, K. Kirk.
Principles of medical imaging / K. Kirk Shung, Michael B. Smith, Benjamin Tsui.
Includes bibliographical references and index
p. cm.
ISBN 0-12-640970-6
1. Diagnostic imaging. 2. Medical physics. I. Smith, Michael B. (Michael Bruce), date. II. Tsui, Benjamin. III. Title.
[DNLM: 1. Biophysics. 2. Diagnostic Imaging--instrumentation.
WN 200 S562p]
RC78.7.D53S52 1992
616.07'54--dc20
DNLM/DLC
for Library of Congress

92-7143
CIP

PRINTED IN THE UNITED STATES OF AMERICA
92 93 94 95 96 QW 9 8 7 6 5 4 3 2 1

Preface

The field of medical imaging is growing at a rapid pace. Since the early 1960s, three new imaging modalities, namely, radionuclide imaging, ultrasound, and magnetic resonance imaging, have appeared and matured. Along with X-ray they are among the most important clinical diagnostic tools in medicine today. Radionuclide imaging, although its resolution cannot match that of other modalities, uses radioactive isotopes attached to biochemically active substances to yield unique information about the biochemical or physiological function of the organ which is unattainable otherwise. Ultrasound scanners use high frequency sound waves to interrogate the interior of the body. They are capable of depicting anatomical details with excellent resolution. Ultrasound is particulary suited to situations where exposure to ionizing radiation is undesirable, such as in obstetrical and neonatal scanning, and to imaging structures in motion, such as heart valves. Magnetic resonance imaging, however, has been envisioned to be the most exciting of them all by far because it also uses a form of nonionizing radiation, can achieve superior resolution, and is capable of yielding physiological information. In this period, significant progress has also been achieved in conventional X-ray radiography. Improved design or introduction of better materials in image intensifiers, intensifying and fluoroscopic screens, and photographic films has enhanced the resolution to a significant degree without adding higher patient radiation exposure levels. It is therefore plausible to understand why conventional radiography is still routinely used clinically for the diagnosis of many diseases and is the gold standard to which newer imaging modalities are compared.

Unquestionably, the digital revolution is the primary reason that has caused the medical imaging field to experience the explosive growth that we are seeing today. Computer and digital technology along with advances in electronics have made data acquisition fast and mass data storage possible. These are the most essential ingredients for the practical realization of tomographical reconstruction principles. X-ray computed tomography (CT), digital radiography, real-time ultrasonic scanners, single-photon emission computed tomography (SPECT), positron emission tomography (PET), and magnetic resonance imaging (MRI), which came about after the early 1970s, are just a few well-known products of the digital revolution in medical imaging.

While the development of these new imaging approaches may have contributed greatly to the improvement of health care, it has also contributed to the rising cost of health care. A chest X-ray costs only \$20–30 per procedure whereas a magnetic resonance scan may cost up to \$1000, let alone the expenses associated with acquiring and installing such a scanner. The cost-to-benefit ratio for

these expensive procedures in certain cases is sometimes not as clear as in others. Therefore it is not unusual that the clinical efficacy and contribution of these modalities to patient care are being scrutinized and debated constantly by the medical community as well as the public.

This book is intended to be a university textbook for a senior or first-year graduate level course in medical imaging offered in a biomedical engineering, electrical engineering, medical physics, or radiological sciences department. Much of the material is calculus based. However, an attempt has been made to minimize mathematical derivation and to place more emphasis on physical concepts. A major part of this book was derived from notes used by the authors to teach a graduate course in medical imaging at the Bioengineering Program of Pennsylvania State University since the late 1970s. This book covers all four major medical imaging modalities, namely, X-ray including CT and digital radiography, ultrasound, radionuclide imaging including SPECT and PET, and magnetic resonance imaging. It is divided into four chapters in which a similar format is used. In each chapter fundamental physics involved in a modality is given first, followed by a discussion on instrumentation. Then various diagnostic procedures are described. Finally, recent developments and biological effects of each modality are discussed. At the end of each chapter a list of relevant references, further reading materials, and a set of problems are given. The purpose of this textbook is to give students with an adequate background in mathematics and physics an introduction to the field of diagnostic imaging; the materials discussed should be more than sufficient for one semester. However, the book may also be used as the text for a two-semester course in medical imaging when supplemented by additional materials or by inclusion of more mathematic detail.

Although this book has been written as a college textbook, radiologists with some technical background and practicing engineers or physicists working in imaging industries should also find it a valuable reference in the medical imaging field. As a final note, it should be pointed out that there are other imaging methods that have been used in medicine [e.g., thermography, magnetic imaging, and microwave imaging (Hendee, 1991)]. They are not included in this book primarily due to their limited utility at present. Readers who are interested in these modalities may refer to several books listed in the following reference section.

References and Further Reading

Barrett, H., and Swindell, W. (1981). "Radiological Imaging: The Theory of Image Formation, Detection, and Processing." Academic Press, New York.

Curry, T. S. III, Dowdey, J. E., and Murry, R. C. Jr. (1990). "Christensen's Introduction to the Physics of Diagnostic Radiology, 4th Edition." Lea and Febiger, Philadelphia.

Freeman, S. E., Fukushima, E., and Greene, E. R. (1990). "Noninvasive Techniques in Biology and Medicine." San Francisco Press, San Francisco.

Hendee, W. R. (1991). *Diagnostic Imaging* **13**, A13.

Huang, H. K. (1987). "Elements of Digital Radiology." Prentice-Hall, Englewood Cliffs, New Jersey.

Jaffe, C. C. (1982). *Am. Scient.* **70**, 576.

Krestel, E. (1990). "Imaging Systems for Medical Diagnosis." Siemens, Aktiengesellschaft, Germany.

Larsen, L. E., and Jacobi, J. H. (1985). "Medical Applications of Microwave Imaging." IEEE Press, New York.

Mackay, R. S. (1984). "Medical Images and Display." John Wiley, New York.